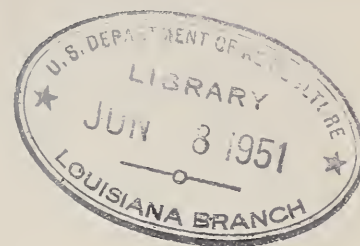


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ROOT-ROT CONTROL AND SOIL IMPROVEMENT AT THE ASHE FOREST NURSERY

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ROOT-ROT CONTROL AND SOIL IMPROVEMENT AT THE ASHE FOREST NURSERY

By

T. E. Maki and Berch W. Henry 1/

The Ashe Nursery near Brooklyn, Mississippi, was established by the United States Forest Service in 1936 on previously unbroken forest soil, classed as a good phase of Ruston fine sandy loam. From the beginning, root rot of undetermined origin caused heavy cull losses of all four species of southern pines (Pinus palustris, P. caribaea, P. taeda, and P. echinata). Even apparently healthy stock showed inferior survival in tests with seedlings from other nurseries. Heavy damping-off (especially sand-splash of longleaf), low fertility, and excessive erosion also hampered production.

"Resting" the nursery during the war did not alleviate the root rot. The first seedling crop after production was resumed in 1945 was heavily diseased, and this, together with the earlier evidence of inferior survival, caused the Forest Service to withdraw the nursery from production until remedies could be found.

1/ Respectively, Officer-in-charge, Gulfcoast Branch of the Southern Forest Experiment Station, and Pathologist, Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering. The authors gratefully acknowledge the unstinting help of R. M. Allen and E. R. Ferguson, who carried out most of the nursery experiments on soil fertility phases, supervised all plantings, made the field examinations, compiled all of the data on soil fertility phases, and prepared many of the basic reports; of Dr. Paul V. Siggers, who made the diagnoses on diseased material and assisted in the early installations on root rot control; of Dr. R. M. Lindgren, who installed the initial pathology tests and who has furnished general supervision and technical guidance generously throughout the whole investigation; and of Nurseryman G. F. Erambert and the Ashe Nursery staff, who carried out all routine nursery operations and without whose full cooperation the successful conclusion of the study would not have been possible.

In November, 1946, the Southern Forest Experiment Station and the Division of Forest Pathology ^{2/} in cooperation with the Mississippi National Forests undertook intensive studies aimed at eliminating the root rot and improving survival of seedlings from the nursery. This report summarizes the results and also the recommendations that were made for controlling root rot and for improving soil fertility at the nursery.

Scope of Past Work ^{3/} and Present Studies

Unexpected losses in the first crop of seedlings at the Ashe Nursery were called to the attention of the Division of Forest Pathology in late 1936 by the Forest Service. For several years thereafter, preliminary investigations were made, but neither personnel nor finances were available for an adequate and continuous attack on the problem. However, among the valuable indications obtained were strong evidence (1) that the disease was infectious and that an organism or organisms were the likely cause; (2) that a combination of soil disinfection and fertilization probably would reduce the disease and increase seedling size. In pot cultures, the disease was found to develop on seedlings sown in soil from infected areas of the nursery. Disinfection of the soil by saturating it with formaldehyde gave disease-free seedlings, but if pieces of infected roots were added to the disinfected soil the disease appeared again. Numerous isolations from infected roots revealed several fungi to be commonly associated with the rot. One of these, Torula marginata, showed some killing of roots when inoculated into soil. Limited experiments indicated that diseased plants were less likely to survive the first year in the field than were healthy plants.

In the early work, no systematic effort was directed toward improvement of soil fertility, although formal tests demonstrated the inferior survival of the Ashe stock as compared to stock from several other nurseries. Some of this inferiority might have resulted from planting stock that was moderately affected with root rot. Nevertheless, by 1939 there was a general feeling that inadequate fertility, perhaps a phosphorus deficiency, also was partly responsible for the poor performance of Ashe stock.

The present study began in November 1946, when 3 beds of longleaf pine were sown on the first area in which severe root rot had been observed. By the spring of 1949 a total of approximately 110 standard nursery beds ($4\frac{1}{2}$ feet by 400 feet) had been sown to longleaf,

^{2/} Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture.

^{3/} Based on office reports and correspondence by Drs. Bailey Sleeth, P. V. Siggers, and Carl Hartley, in the files of the Division of Forest Pathology. This early work also was summarized in a report "Root Rot at the Ashe Nursery, Brooklyn, Mississippi", October 15, 1946, by Dr. Curtis May of the Division of Forest Pathology.

slash, and loblolly pine in various tests on root-rot control and improvement of soil fertility. These beds produced an estimated three and a half million seedlings of plantable size. Over 200 thousand sample seedlings were individually handled or examined, and of these, over 100 thousand had been outplanted by December 1949 in well-replicated experimental plots on the Desoto National Forest.

Root Rot

The large number of individual tests in the study makes it impractical to report on each of them. Only enough tabular material is included to illustrate the nature and magnitude of response to the different treatments.

Occurrence, nature, and effect

Study of root rot was confined to three pine species, longleaf, slash, and loblolly. All were susceptible to root rot, but not equally so. In spots where the disease was severe, loblolly showed 50 percent mortality in the seedbed; and spring-sown longleaf was not worth lifting because 90 percent or more of the seedlings had to be culled for tap roots and scarcity of laterals. In such spots 95 percent of the slash pine were sometimes affected, but seedbed mortality was usually light, and cull percent never approached the extreme mentioned for spring-sown longleaf.

The rot was unevenly distributed through the nursery. Tests in four out of ten 9-acre compartments have shown that the disease was heavy in compartment 7 (where it was first observed), moderate in compartment 2, and very light and spotty in compartments 5 and 6.

The rot could not be detected by surficial examination of seedbeds. Badly infected seedlings often attained large size and their foliage and shoots appeared vigorous.

In grading seedlings for outplanting tests, six classes of rot were recognized for longleaf pine, five for slash and loblolly.

These classes are:

1. Healthy.
2. Up to 25 percent of tap root surface affected.
3. 26 to 50 percent of tap root surface affected.
4. Over 50 percent of tap root surface affected.
5. Lower part of tap root dead, and proliferation of laterals from live portion.
6. Entire tap root surface affected, and 3 or less living laterals; occurs only in longleaf.

In general, the more severely longleaf seedlings were infected, the poorer they survived in the field (table 1). The survival of even the most lightly affected stock was 25 percent lower than that of healthy seedlings. The exception was class 5 seedlings, which frequently had as many or more laterals than were found on healthy ones, so that careful planting allowed fair survival even though the root systems were shallow.

Table 1.--Average survival of outplanted seedlings that showed various stages of root-rot damage when outplanted, but which were plantable on a size basis. All seedlings were from untreated nursery beds

Year planted, species, and time in field ^{1/}	Root-rot class ^{2/}					
	1	2	3	4	5	6
	----- <u>Percent</u> -----					
1948 ^{3/}						
Longleaf						
5 mos.	89	82	70	59	84	44
12 mos.	77	52	41	28	53	8
Slash						
5 mos.	93	97	96	91	92	...
12 mos.	84	90	91	77	72	...
1949 ^{3/}						
Longleaf--4 mos.	93	96	93	82	95	46
Slash--4 mos.	99	99	97	93	100	...
Loblolly--4 mos.	97	98	99	93	99	...

- ^{1/} Eight replicates of 25 seedlings each in 1948 outplanting and 4 replicates of 25 seedlings each in 1949 outplanting.
- ^{2/} For definition of classes, see page 3.
- ^{3/} Results for the 1948 tests in this table are reported as actual mean survival percents; for the 1949 tests, and for all other tests in subsequent tables, unless otherwise specified, the percents refer to mean proportions of seedlings in fair and better vigor--which is roughly equivalent to expected survival at the end of the second season in the field.

Only the more severely affected slash seedlings showed reduced survival after 12 months in the field. From the meager evidence available, loblolly seemed to react similarly to slash. From both condition in the nursery and survival in the field, it appears that the root rot affects spring-sown longleaf most, loblolly next, and slash the least.

Cause of disease

The cause of root rot has proved elusive. There is strong evidence that a nematode-fungus complex is involved. Three species of fungi (Torula marginata, Sclerotium bataticola, and Fusarium sp.) and representatives of at least ten genera of nematodes (Acrobeloides, Ditylenchus, Aphelenchoides, Panogrolaimus, Tylenchus, Pratylenchus, Discolaimus, Dorylaimus, Diplogaster, and Zeldia) have been found associated with diseased roots. However, inoculation with various of these organisms, alone and in combination, has not completely reproduced the disease symptoms.

Methods of control

Root-rot control has been attempted with various fertilizers and soil amendments, with varying dates of sowing, with fungicides, nemacides, and an insecticide incorporated into seedbeds prior to sowing. Of these approaches, three have given fair to excellent control:

1. The nemacidal fumigant ethylene dibromide ($\text{BrCH}_2\cdot\text{CH}_2\text{Br}$) at rates of 30 to 32 gallons per acre of a 20 percent by volume solution (Dowfume W-40);
2. Fall sowing of longleaf; and
3. Sawdust at the rate of 10 or more tons per acre combined with various minerals disked into the surface six inches of soil.

Fumigation.--The nemacidal fumigant, Dowfume W-40, has given the best results; it has consistently controlled the disease in all trials over a 3-year period (1947-1949). Some other soil fumigants have also shown promise (table 2); none have been superior to ethylene dibromide, and none have equalled it in low cost, ease of application, and slight hazard to personnel.

Seedlings from beds treated with ethylene dibromide have, in almost every instance, survived better when outplanted (table 3)--mainly, no doubt, because they were free from disease.

On bed segments given one treatment with ethylene dibromide, roughly 35 percent more plantable seedlings were produced in 1949 than on bed segments left untreated (table 4). Where ethylene dibromide was applied on the same area in two successive seasons without intervening cover and green manure crops, there was no deleterious effect on pine seedlings. Neither was there any appreciable carry-over of disease control to the second pine seedling crop on small plots that received no additional fumigation the second year (table 4). In current nursery practice, at least one year in cover crops would intervene between pine crops. Thus, although it may be necessary to fumigate diseased areas of the nursery prior to each spring-sown pine crop, no harmful effects from build-up of the chemical are anticipated.

Table 2.--Materials used in soil treatments for root-rot control and their relative effectiveness ^{1/}

Fumigants		Non-fumigants	
Chemicals and rate of application per acre	Effect-iveness	Chemicals and rate of application per acre	Effect-iveness
Ethylene dibromide (20 percent by volume)		Formaldehyde (40 percent by weight)	
25 gal.	3	250 gal.	1
32 gal.	4	Allyl alcohol	
41 gal.	4	20 gal.	1
		30 gal.	1
Methyl bromide gas		40 gal.	1
218 lbs.	3	50 gal.	1
435 lbs.	4	Ethyl mercury iodide	
870 lbs.	4	150 lbs.	0
Chloropicrin		Salicylic acid	
41 gal.	3	240 lbs.	0
Dichlorobutene		(Arasan) 50 percent tetramethyl thiurandisulphide	
50 gal.	2	150 lbs.	0
Dichloropropane-dichloropropene		(Dithane D-14) sodium ethylene bisdithiocarbamate	
50 gal.	0	150 lbs.	0
Allyl bromide		(Dithane Z-78) zinc ethylene bisdithiocarbamate	
25 gal.	2	150 lbs.	0
		Zinc trichlorophenate	
		150 lbs.	0
		Ferrous sulphate	
		4,000 lbs.	0
		(Spergon)	
		Tetrachloroparabenzoquinone	
		150 lbs.	0
		(Ferbam) ferric dimethyldithiocarbamate	
		150 lbs.	0
		DDT	
		50 lbs.	0

^{1/} Effectiveness on 0-4 scale: 0 = no control, 4 = excellent control.

Table 3.--Effects of ethylene dibromide on production of l-0 seedlings, incidence of root rot, and survival in the field

Species and test	Seedbed density		Av. green weight of plantable seedling	Av. proportion of healthy + lightly affected	Field survival
	Total	Plantable			
	No. per sq. ft.		Grams	Percent	Percent
<u>Longleaf</u>					
Test 4.4-0; 1949					
Treated	17	13	11.4	100	96
Untreated	8	2	10.1	5	80
Test 4.4-h; 1949					
Treated	38	26	10.4	100	85
Untreated	38	20	8.7	28	79
<u>Slash pine</u>					
Test 4.4-h; 1948					
Treated	28	24	6.1	75	<u>1/</u> 91
Untreated	28	21	6.4	20	<u>1/</u> 83
Test 4.4-h; 1949					
Treated	30	22	9.8	99	83
Untreated	27	16	9.9	31	82

1/ Fair and better vigor 12 months after planting; all others four months after planting.

Table 4.--Effects of treatment and re-treatment with ethylene dibromide in an area of moderate root-rot occurrence. Data taken from 1949 pilot-plant experiment, representing four replicates per species per treatment

Treatment	Plantable		Root rot		Survival	
	Longleaf	Slash	Longleaf	Slash	Longleaf	Slash
	Number <u>1/</u>		Index <u>2/</u>		Percent <u>3/</u>	
Not fumigated	20	16	57	57	35	85
Fumigated 1948	19	20	44	50	45	85
Fumigated 1949	26	23	1	2	76	85
Fumigated 1948 and 1949	19	21	2	1	75	85

- 1/ The number of plantable seedlings per square foot of nursery bed at lifting time, graded on the usual size and vigor basis.
- 2/ The severity of root rot on the plantable seedlings on a 0-100 scale; 0 = free from root rot and 100 = taproot entirely affected and lower part dead.
- 3/ Expected field survival at 12 months obtained by interpolating the root-rot index onto the survival data in table 1.

Since in two successive seasons ethylene dibromide applications to areas of known heavy infection gave higher yields of plantable seedlings which were virtually rot-free, the effectiveness of fumigation as a practical control measure seemed amply demonstrated and led to the development of the Ashe Fumigator. This is a fumigation rig that fits on a Farmall H tractor. A pump, attached to the power-takeoff of the tractor, delivers the chemical from a 50-gallon drum back of the driver's seat to a boom attached to the hydraulic lift under the tractor. Two rows of shanks, 4 and 3 per row with a lateral spacing of 10 inches, are also attached to the lift. Down the back of each shank is a metal tube with a nozzle just back of the point of the shank. The chemical is carried by individual hoses from the boom to the tube of each shank. The shanks are inserted 6 inches into the soil when the machine is operating. A small cultipacker is attached to the rear of the tractor to seal the furrows left by the shanks. The outfit can operate at approximately 4.7 miles per hour, and at this speed will treat a 6- by 415-foot nursery bed in approximately one minute.

Fall sowing.--Fall sowing has given about as striking control of root rot as has fumigation with ethylene dibromide. Unfortunately, longleaf is the only southern pine that is sown in substantial amounts in the fall.

The effectiveness of fall sowing has been observed and recorded in two compartments. In compartment 7, where infection has been heavy, only about 1/3 of untreated spring-sown longleaf was graded as either healthy or with only light infection, whereas untreated fall-sown longleaf in adjacent beds was nearly all healthy or only lightly affected (table 5).

Table 5.--Comparative data on untreated spring- and fall-sown longleaf pine at the Ashe Nursery (1946-1947)

Season of sowing	Seedbed density		Average green weight per plantable seedling	Proportion of plantable seedlings healthy or only lightly affected ^{1/}	Survival ^{2/}
	Total	Plantable			
	-- Number --		Grams	Percent	Percent
Spring	7	6	15.5	35	65
Fall	37	34	10.0	98	76

^{1/} Affected seedlings had such slight rot that they would have passed ordinary inspection at the nursery grading table.

^{2/} 12 months after planting.

Sawdust.--The organic soil amendments tested in combination with mineral fertilizers included Masonite sludge, hardwood leafmold, and sawdust. Although all three organics reduced root rot, only sawdust gave evidence of fairly large benefits. The reduction in root rot was particularly noticeable in spring-sown longleaf and in loblolly pine (table 6). Three times as many spring-sown longleaf in sawdust-treated plots were healthy or only lightly affected, in contrast to seedlings from check plots; similarly, in loblolly pine, sawdust plots had five times as many healthy or only lightly infected seedlings as were found in check plots. With spring-sown longleaf, the sawdust treatments also improved field vigor slightly, but with loblolly and slash pine there was a slight reduction. The reduced survival in outplantings should not be construed as indicating that sawdust is harmful, since other tests, using a more nearly optimum combination of fertilizer and organic amendment, have shown treated seedlings to survive as well as or better than checks.

Since there is much yet to be learned about continuous application of sawdust to nursery soils and since residual effects of sawdust on incidence of disease have not been determined, it is too early to recommend its use as a major control measure. For the present, main reliance for control of root rot is appropriately placed on fumigation in spring sowings, and on fall sowing by itself.

Seedling Production and Quality

Comparison of Ashe and Stuart stock

Prior to 1942, Ashe stock had been found inferior to that from several other nurseries, including the Stuart Nursery at Pollock, Louisiana. For example, in a 1941 test when the stock was graded by identical standards and planted in intermingled rows, this inferiority was quite marked. First-year survival of Ashe longleaf was only 67 percent, in contrast to 93 percent for Stuart longleaf. It was deemed advisable to determine whether such differences still existed.

Comparisons between Ashe and Stuart stock from untreated beds were made both in the 1947 and 1948 plantings. In the 1948 test, which was the more comprehensive, Ashe longleaf samples showed almost 3 times more plantable seedlings per square foot (40 vs. 15), yet produced nearly as heavy seedlings (10.4 grams vs. 10.7 grams, green weight) and slightly better first-year survival (78 percent vs. 73 percent). For slash pine, Stuart samples showed a slightly higher bed density, but seedlings were less than half as heavy as those from the Ashe. Although survival of Stuart slash was about 9 percent higher (85 percent vs. 76 percent), first-year growth was slightly less (2 inches against 2.5 inches). Both survival and growth differences were mainly attributable to the difference in seedling size at time of planting.

Table 6.--Effect of various sawdust treatments on seedling production and incidence of root rot

Species and treatment number <u>1/</u>	Seedbed density per square foot		Av. green wt. per plantable seedling <u>Grams</u>	Proportion healthy and lightly affected <u>2/</u> <u>Percent</u>	Survival <u>2/</u>
	Total	Plantable			
	- - <u>Number</u> - -			- - <u>Percent</u> - -	
<u>Spring-sown longleaf</u>					
1 (check)	6.3	5.6	14.4	22	62
14	8.0	7.5	18.6	63	67
15	6.3	5.8	16.8	50	65
16	5.4	5.2	19.6	76	74
Mean of treated	6.6	6.2	18.3	63	69
<u>Slash Pine</u>					
1 (check)	27	21	6.0	74	87
14	35	25	4.8	92	83
15	26	20	5.5	88	81
16	26	21	4.8	99	79
Mean of treated	29	22	5.0	93	81
<u>Loblolly</u>					
1 (check)	28	20	3.5	18	91
14	60	34	2.0	81	76
15	43	31	2.6	86	80
16	44	28	2.0	95	94
Mean of treated	49	31	2.2	87	83

1/ 1--Check; nothing added. Last pine crop in 1941. Since then cover and soiling crops plowed under each year.

14--Sawdust at 15 tons per acre plus a complete fertilizer (5-25-15) (including minor elements) at 800 lbs. per acre, and formaldehyde at the rate of $\frac{1}{2}$ fluid ounce per square foot.

15--Sawdust at 15 tons per acre plus complete fertilizer as in 14.

16--Sawdust at the rate of 30 tons per acre plus ammonium nitrate at the rate of 240 pounds NH_4NO_3 salt per acre.

2/ 12 months after planting.

Fluctuations in seedling quality occurred between years and species, but Ashe stock no longer appeared inferior. In fact, when stand density and seedling size are also taken into consideration, any basis for inferiority of either slash or longleaf stock from the Ashe disappears.

Seedbed density

A record of seedbed densities, both total and plantable, at lifting time is essential to a clear understanding and evaluation of nursery production. One of the most important factors in the cost of planting stock is the number of plantable seedlings produced per unit area. An increase of one plantable seedling per square foot in the seedbed means 32,400 additional seedlings per nursery acre--about enough trees to plant 30 acres. All major items of nursery costs remain about the same whether the plantable seedling stand is 30 per square foot (972,000 per nursery acre) or only 10 per square foot (324,000 per nursery acre).

Our knowledge of the essential qualifications of plantable seedlings is still very nebulous, as is our knowledge of the optimum densities for southern pine nursery stock. Until better information is available, the "standard" of 30 plantable seedlings per square foot may be used, but this figure is possibly high, unless total density is not more than about 35 seedlings per square foot.

Extensive sampling of seedbeds in four Ashe Nursery compartments over the past three years has revealed considerable variation in total numbers of seedlings as well as in number of plantable seedlings per square foot. In general, the highest proportion of plantable seedlings has been obtained from fall-sown longleaf, but spring-sown longleaf has yielded somewhat higher total bed densities (table 7). In number of plantable seedlings, loblolly has usually ranked a poor third. Except in loblolly pine, there has been no pronounced relationship of proportion of plantable seedlings to seedbed density in beds subjected merely to standard nursery practices.

Despite uniform treatment, the check plots from various tests in the Ashe study displayed about a hundred percent range in seedbed density, but there was no consistent trend in proportion of plantable seedlings or in seedling size for either spring or fall-sown longleaf or for slash pine. In all probability this mainly reflects the large variation in fertility levels, in tilth, erosion, drainage, and the like, within and between beds and compartments under the existing soil management practices at the Ashe, as well as differences caused by such agencies as damping-off. In this connection, allyl alcohol used at rates from 35 to 50 gallons per acre (applied at least 3 days before sowing and in water solution at the rate of one quart per square foot) gave promise of reducing stand losses due to damping-off, sand-splash, and weed competition or removal during the first few months after sowing. This material, its hazards being recognized, would deserve further trial at the Ashe or elsewhere if damping-off became troublesome or if for some reason early weed control could not be handled satisfactorily by the cheaper mineral oil sprays.

Table 7.--Number, proportion, green weight, and survival of plantable longleaf, slash, and loblolly pine seedlings from Ashe Nursery check plots, 1947-1949

Species	Seedlings per square foot			Average green weight per plantable seedling	Survival <u>1/</u>
	Total	Plantable			
	<u>Number</u>	<u>Number</u>	<u>Percent</u>	<u>Grams</u>	<u>Percent</u>
<u>Longleaf</u>					
Fall-sown	37	32	86	10.6	80
Spring-sown	39	31	78	9.0	78
<u>Slash Pine</u>	35	25	73	6.8	82
<u>Loblolly Pine</u>	23	18	78	5.9	88

1/ 12 months after planting.

Seedling size

In grading stock for the various tests in this study, the rules of Region 8 (U. S. Forest Service) for minimum size, based mainly on diameter at root collar, on root length, and on height of stem (length of needles for longleaf pine), were followed except that root lengths as short as 4 inches were included in the samples. Plantable stock was not separated by grades, and seedling size was determined by weighing (to the nearest gram) bundles of 26 seedlings each, then computing average green weight per seedling.

On this basis, large variations in seedling green weight were found in different parts of the four compartments where test beds were located. The green weight of plantable fall-sown longleaf averaged about 10.6 grams per seedling against 9 grams for spring-sown longleaf; slash pine averaged about 6.8 grams, and loblolly about 5.9 grams (table 7). As might be expected, seedling weights tended to vary inversely as the seedbed density, but except for extreme densities and for loblolly pine, the trend was not pronounced.

These weights of seedlings were produced on ground that had "rested" over the war years. Despite the presumably high level of fertility resulting from the rest period, during which standard nursery fertilizing practices were applied, the average size of the seedlings appears to be small. However, lacking any record of seedling size produced in the pre-war pine crops at the Ashe, it is conjectural whether current seedling crops are heavier or lighter.

Seedling quality (or hardiness)

Quality or hardiness of seedlings from the Ashe, as from any nursery, is only partly related to size and seedbed density. Although size is very important, the fact that seedlings are large is no guarantee that they will do well when planted. Large seedlings of any given lot usually survive less well than smaller seedlings of the same lot; however, the large survivors do grow much better after they are well established.

Efforts to improve seedling quality were confined in the main to application of various mineral elements alone and in combination with organic soil amendments. Because fertility undoubtedly rose during the long rest period, it is not surprising that these soil improvement efforts over a short period of three years did not produce startling results.

Minor elements.--In two years of testing, no evidence was found that the Ashe soil was suffering from any deficiency of boron, manganese, copper, magnesium, iron, or zinc. For Mississippi soils in general, there are no reports of deficiencies of minor elements, except of boron on limed soils. The Ashe results, therefore, accord with agronomic experience and study.

Nitrogen.--In the history of nursery fertilizing programs, nitrogen has frequently been the major element used in attempts to improve seedling size and vigor. In this study, nitrogen alone rather consistently failed to boost seedling growth and usually lowered vigor of outplanted seedlings somewhat. When applied with superphosphate and potash, the mixture increased seedling size very markedly, sometimes by more than 50 percent over check seedlings. The increased size was usually associated with some reduction in bed density, particularly where nitrogen was applied before sowing. On the whole, experience with nitrogen at the Ashe showed that only in special instances, as in correcting deficiency due to a high carbon-nitrogen ratio, was it worthwhile to apply this element alone.

Phosphorus.--Current study supported the early postulations of phosphate deficiency and indicated that past phosphorus fertilizing confined to cover and green manure crops was inadequate. Phosphorus alone seldom showed much benefit, but when applied with nitrogen, or with nitrogen and potash, consistently improved seedling growth. Frequently, the combined application also improved field vigor or survival. Rates of application up to 4,000 pounds of 20 percent superphosphate per acre gave no indication that a ceiling to phosphate response had been reached. Previous applications had never exceeded 600 pounds per acre per year. This suggests that Ashe soils may have been suffering from fairly acute phosphorus deficiency for a number of years.

In most tests, superphosphate was applied broadcast before sowing and disked into the surface 6 inches of soil. This practice was regarded as desirable because it was assumed that the high phosphate-fixing capacity of Coastal Plain soils would greatly hinder the downward movement of any phosphorus applied only to the surface. Recent tests, however, have indicated marked response to side dressings containing phosphates (table 8). In southern nurseries, if post-sowing applications of fertilizers are required in areas not recently fertilized with phosphates, it is well to include superphosphate with the other mineral side dressings.

Table 8.--Improvement in vigor of spring-sown longleaf pine from post-sowing applications of nitrogen, phosphorus, and potash

Nursery bed treatment <u>1/</u>	Seedlings in fair and better vigor 4 months after planting <u>2/</u> Percent
Check	44
Nitrogen alone	44
NPK ₁	53
NPK ₂	69
NPK ₄	63
NP	69

1/ Ammonium nitrate at 175 pounds N per acre; superphosphate at 800 pounds P₂O₅ per acre; muriate of potash at the following rates:

K₁ = 120 pounds K₂O per acre

K₂ = 240 pounds K₂O per acre

K₄ = 480 pounds K₂O per acre

2/ Based on six nursery and six field plots.

Potash.--Bits of evidence from the Ashe study, but more specifically from some other studies at the Gulfcoast Branch, indicate that some potash is required to offset possible deleterious effects of excessive nitrogen. In other words, potash is probably worth adding as insurance that seedlings will harden off adequately, since potash is assumed to play a role in drought-hardiness. The right amount of potash for best results has not yet been determined, but the data in table 8 suggest that 480 pounds K₂O per acre is too high. For a safe annual dosage, probably 120 pounds K₂O per acre (equivalent to 240 pounds 50 percent muriate of potash) may be close to the optimum for Ashe soils.

Organic amendments.--Three main types of organic amendments were tested under various conditions: hardwood leafmold, Masonite wood flour (Benaloid 1,000), and sawdust. In heavily diseased areas, all organics reduced root rot somewhat, but in other areas benefits were variable. All improved the tilth of heavy areas very materially, making lifting easier, and although no measurements were made, root development appeared to be better in plots so treated.

Hardwood leafmold was tried without any manurial additions on the assumption that it was probably pretty well balanced and possibly would introduce desirable organisms into the nursery soil.

The amount of improvement in seedbed density and seedling weight and vigor from leafmold applications was fairly consistent, although not large. Leafmold is unquestionably a safe material to use in seedbed improvement or in treatment of gall spots.

Masonite wood flour, a "waste" by-product from the Masonite process, is a brown impalpable powder, resistant to wetting and to rapid decay.

If satisfactory application methods can be developed (it is hard to handle on windy days), and the material is worked into the soil thoroughly long enough in advance of sowing to permit good wetting, it is believed that wood flour will improve soil tilth and make mineral fertilizers go further.

The beneficial effects of sawdust in reducing root rot have already been described. Other benefits are unmistakable improvement of soil tilth, seedling size, and vigor.

Bed densities in sawdust-treated plots varied from lower to higher than in check plots. No clear evidence was obtained to determine whether old sawdust (about 15 years) was better than new-fallen kerf, nor was there definite indication that hardwood sawdust was inferior to pine.

None of the sawdust tests were carried far enough to determine whether any deleterious residual effects develop or how frequently sawdust should be applied. Neither was it possible to determine whether it was better to apply sawdust directly to pine crops or to green manures. The one instance where sawdust and minerals were applied before sowing of field peas gave very promising results. The main effect of sawdust and fertilizers was to prolong the period of growth of field peas, which stayed green about a month longer than those receiving standard Ashe Nursery practice and those that received an additional light application of nitrogen. Fall and spring sowings of longleaf and spring sowings of slash pine which followed the crop of field peas grew to very creditable size without additional fertilizers.

In general, the tests showed that sawdust reduces root rot in heavily diseased areas, improves soil tilth, affords a rapid means for raising soil organic matter content, and increases seedling size and vigor if combined with proper additions of nitrogen, phosphorus, and potash. Most of these initial benefits may reasonably be expected to hold in a continuous nursery soil management program.

Time of application.--When should minerals be applied in relation to sowing of seed? This is a question of great practical significance. Obviously if minerals are to be added to soils, it is cheapest and simplest to add them dry before the beds are made up.

The Ashe study gave an opportunity to probe into this problem in several tests, although not so thoroughly as the problem warrants. Most minerals reduce bed density if applied before sowing (table 9). Lime applied before sowing caused a sizeable reduction, but when applied after sowing is certainly not harmful and may be beneficial. Like superphosphate, it can be applied dry with any suitable machinery; hence it is one of the safest materials for side dressings in acid soils where late-season damping-off may not be important.

Table 9.--Effect of pre-sowing and post-sowing applications of various minerals on final densities of seedbeds of fall-sown longleaf

Treatment	Seedlings per square foot				Av. green wt. per plantable seedling	
	Total		Plantable		Pre-sowing	Post-sowing
	Pre-sowing	Post-sowing	Pre-sowing	Post-sowing		
	- - - - - <u>Number</u> - - - - -				- - <u>Grams</u> - -	
Check	21	26	19	24	13.5	12.7
Lime <u>1/</u>	12	26	12	24	24.2	14.4
Gypsum <u>2/</u>	27	24	27	23	11.7	13.6
Lime + boron <u>3/</u>	12	26	11	24	24.2	13.8
Florida sand special <u>4/</u>	18	24	18	23	17.4	15.3
Epsom salts <u>5/</u>	20	27	18	25	16.4	14.8
Mean	18	26	18	24	17.9	14.1

- 1/ Lime applied at the rate of 640 pounds dehydrated lime per acre.
2/ Gypsum applied at the rate of 1,400 pounds $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ per acre.
3/ Lime + boron applied at the rate of 640 pounds lime plus 15 pounds $\text{Na}_2\text{B}_4\text{O}_7 \cdot \text{H}_2\text{O}$ per acre.
4/ Florida sand special at rate of 400 pounds 6-6-6 (+ minor elements).
5/ Epsom salts at rate of 1,400 pounds $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ per acre.

Heavy dosages of nitrogen before sowing may also appreciably reduce bed densities. Unlike lime or superphosphate, nitrogen side dressings (and similarly potash) require care in application to prevent foliage burn. Probably the safest way is to apply them in solution and then to rinse the foliage adequately.

Pre-sowing applications frequently produced larger seedlings, but this was probably due to lower bed densities as much as to the time of application. The chief question is whether seedling quality was related to time of fertilizer application. In some tests pre-sowing applications produced seedlings of better field vigor, but the differences were not large. Seedlings side-dressed early in the season appear to be hardier than seedlings side-dressed late.

Nursery drain.--The Ashe study yielded considerable data on nursery drain in terms of green and dry weight of plant material removed. As adequate tissue analyses were not made, little can be said about the amounts of nutrients actually being removed by individual pine seedling crops. We may surmise at this stage that the amounts are quite large.

Nearly 6 tons (dry weight) of plant material are removed per acre, assuming a production of a million seedlings averaging 15 grams green weight per seedling. Naturally, these figures change as the seedling weights and bed densities change. If we assume that the average N, P, and K contents of dry seedlings are 1.2 percent, 0.2 percent, and 0.5 percent, respectively, a six-ton seedling crop removes 144 pounds nitrogen, 56 pounds P_2O_5 , and 72 pounds K_2O per acre. Since the efficiency and recovery of the various fertilizers in pine seedling production are not known, we may only guess as to how much should be added to the soil each year for continuous crops of pine. Rates of 100 to 300 pounds N, 120 to 300 pounds K_2O , and 400 to 800 pounds P_2O_5 were used at the Ashe, and may represent desirable working ranges fairly closely, depending on condition of soil, degree of erosion, and similar factors.

Erosion is one of the most important agencies altering the quality of seedbeds in any nursery located, like the Ashe, on rolling land; the soil management program must be geared first to deal effectively with this problem before improvement in other aspects of soil management can be fully achieved.

Recommendations

Following are, in brief, the recommendations made to the Ashe Nursery as a result of this study. The problem at the Ashe is perhaps not unique; the remedial measures outlined here may possibly find wider application, particularly in other southern nurseries.

Recommended procedure for control of root rot

1. Fall-sown longleaf.--Where longleaf is fall-sown, no further precaution against root rot is deemed necessary.

2. All spring-sown species.--Areas with previous root-rot history and other areas initially used for spring-sown species should be fumigated with ethylene dibromide. When the severity of disease occurrence is not known, it is suggested that a few scattered beds be left untreated for the initial crop. If the disease does not appear or is only light in the untreated beds of an area, it is suggested that such an area be left untreated for the next pine crop and for subsequent pine crops until the severity of root rot warrants the control

treatment. Fumigation of the initial pine crop, and as warranted for subsequent crops, should be carried out as follows:

Material: Ethylene dibromide. Dowfume W-40 was the form used in all experimental trials. A more concentrated form of the chemical, Dowfume W-85, is now available and it is suggested that this form be used because of the savings in cost, freight, and storage space.

Cost of material in 1949: Dowfume W-40, \$1.92 per gallon; Dowfume W-85, \$4.45 per gallon. The latter is approximately the equivalent of paying \$1.40 per gallon for W-40.

Rate of application: 30 gallons per acre of W-40 or 9 gallons per acre of W-85. The latter may be diluted with mineral spirits, 3 parts to 7 parts respectively, to give a concentration equal to the W-40 if application of the larger quantity (30 gallons per acre) should prove more feasible.

Time of application: October or later, allowing at least a 3-week waiting period between fumigating and sowing pine.

Method of application: By use of the Ashe Fumigator. This machine delivers the fumigant in a continuous flow, at a depth of 6 inches, with 10-inch spacing between rows, and treats a strip 6 feet wide. Thus, one trip with the machine treats one bed width from center of alley.

Condition of soil at time of treatment: The soil should be tilled as for planting but the beds should not be thrown up; soil should be moist but workable; the soil temperature should be between 50° F. and 75° F.

Working soil after treatment: Immediately prior to sowing, the soil may be worked to a depth not to exceed that at which the fumigant was injected. Working the soil, such as is done in throwing up the seedbeds, probably allows the dissipation of any remaining fumigant and thus forestalls possible chemical damage to the pine seedlings.

Recommended procedures for improvement of soil fertility

Several conditions or situations exist or may develop at the Ashe Nursery, each requiring somewhat different soil-management practices.

On much of the still-arable portion of the nursery, no pine or other crops have been removed for several years. These areas may need only addition of minerals before sowing the first new pine crop following the rest period.

On areas where a pine crop has been harvested from rested land, it is recommended that after the pine crop sawdust and minerals be applied, followed by soiling crops for one season. This treatment would precede a 2:1 rotation of pine and green manure cover crops.

Occasionally it may be necessary to sow consecutive crops of pine on areas which have not been amended with sawdust. Such areas can be treated to advantage with sawdust and minerals before sowing the second pine crop.

When seedlings get off to a slow start or fail to maintain thrifty growth, suitable side dressings should be applied.

Finally, where gall spots have formed, heavy applications of sawdust or leafmold with appropriate mineral additions may restore seedling production to a satisfactory level.

The recommended procedures for each of the situations or conditions described in the foregoing paragraphs are specified below:

1. Where minerals are applied to rested areas before sowing pine (applies to most of the Ashe Nursery not in seedbeds during 1950).

(a) Add 3,000 pounds 20 percent superphosphate (600 pounds P_2O_5) and 240 pounds 50 percent muriate of potash (120 pounds K_2O) per acre broadcast before disking, then disk into surface 6 inches of soil. In fertile areas, the dosages may be reduced to 2,000 pounds superphosphate (400 pounds P_2O_5) and 200 pounds KCl (100 pounds K_2O) per acre.

(b) About 15 days after germination (burlap removal), add 100 pounds ammonium nitrate (approximately 35 pounds N) per acre in liquid form, rinsing foliage immediately after application. Repeat this process 2 more times at 15-day intervals.

2. Where sawdust and minerals are added before sowing area to field peas or other green manure crop. (This treatment applies to areas in seedbeds during 1950, and to most of the Ashe after the first "post-rest" pine crop has been harvested. In general, it is the most attractive treatment because it should require no side dressing, and at least in the better compartments can be used on a 2:1 rotation of pine versus soiling crops.)

(a) Broadcast sawdust at the rate of 20 tons (equivalent to a 1-inch layer or 135 cubic yards) per acre.

(b) Broadcast 600 pounds ammonium nitrate per acre and 300 pounds 4-8-8 commercial mix.

(c) Disk sawdust and minerals into surface six inches of soil at least two weeks before sowing field peas.

(d) Sow field peas on regular schedule. If two pea crops are sown in the same season, add 300 pounds 4-8-8 commercial mix with second sowing of peas.

(e) When peas are ready to plow under for fall sowing of pine, broadcast 3,000 pounds 20 percent superphosphate and 240 pounds 50 percent muriate of potash per acre, then plow or disk field peas and fertilizers into surface six inches of soil; follow by sowing to pine.

If area is to be sown to pine in the spring, plow field peas under in the fall in usual manner, adding only the regular 300 pounds 4-8-8 commercial mix for the winter cover crop. Before cover crop is plowed under the following spring, broadcast the 3,000 pounds 20 percent superphosphate and the 240 pounds 50 percent muriate of potash, then work both cover crop and minerals into soil in preparation for spring sowing of pine.

(f) No side dressing should be necessary for the first pine crop following the above treatment. However, if during the growing season areas show up where seedlings look pale and unthrifty, add nitrogen at rates and intervals as listed under 1-b.

(g) After the first pine crop is harvested, the same area may be used for spring sowing of a second consecutive pine crop. Before sowing pine, broadcast 3,000 pounds 20 percent superphosphate and 240 pounds muriate of potash per acre as under 1-a, disking same into surface six inches of soil. Side dress in the second growing season as under 1-b only if the seedlings fail to develop in a reasonably thrifty manner.

(h) After the second pine crop is harvested, start sawdust and mineral treatment all over again as in 2-a through 2-c; then sow field peas, and follow through as in 2-d to 2-g, inclusive.

(Note: If compartments have been badly depleted by erosion it is recommended to skip the second consecutive pine crop, and follow a 1:1 rotation a second round before shifting to a 2:1 rotation of pine and green manure.)

3. Where minerals are applied with sawdust before sowing pine (this applies to areas needed for pine production before there is an opportunity to go through the sawdust-mineral-green manure programs):

(a) Apply sawdust at the same rate as under 2-a, and superphosphate and muriate of potash as under 1-a. Disk all three materials into surface soil.

(b) Begin adding nitrogen 15 days after burlap removal and continue as under 1-b. If yellowing shows up after July, make additional applications of nitrogen until greenness is restored.

4. Where all minerals are added in post-sowing application (this treatment is recommended for individual beds where seedlings are small and lack good color):

Apply 20 percent superphosphate in dry form at the rate of 1,600 pounds per acre (320 pounds P_2O_5). Follow up P_2O_5 application with muriate of potash at the rate of 120 pounds per acre (60 pounds K_2O), and ammonium nitrate at the rate of 100 pounds per acre (35 pounds N), with both KCl and NH_4NO_3 mixed in the same water solution and applied by gravity feed from a tank on a tractor-drawn dolly. Rinse foliage

immediately after application. Repeat above dosages two or three times at 15-day intervals until seedling thrift appears satisfactory.

5. Where subsoil is exposed by erosion, or where areas of heavy soils or excessive crusting occur because of erosion or other reasons:

(a) If leaf mold is available, apply locally in 2-inch layer (about 270 cubic yards per acre); broadcast 20 percent superphosphate at the rate of 4,000 pounds per acre (800 pounds P_2O_5) and 50 percent muriate of potash at the rate of 400 pounds per acre (200 pounds K_2O). Disk leafmold and minerals thoroughly into surface six inches of soil, then sow to pine if needed, otherwise to green manure or cover crop in the regular manner.

(b) If sawdust is used, apply at the same rate as leafmold above; add superphosphate and muriate of potash also as in 5-a above, plus ammonium nitrate at the rate of 600 pounds (200 pounds N) per acre. Work sawdust and all minerals thoroughly into surface six inches of soil. If area is needed for pine, wait at least 3 weeks before sowing. (It is preferable to follow treatment with green manure or cover crop sown in the usual manner before using area for pine seedlings.)

(c) Repeat treatment 5-a or 5-b in successive years until mellowness and good tilth of gall spot are restored.

N.B.: In all instances, if the analyses of the fertilizers obtainable at any given time differ from those prescribed, appropriate adjustments in dosages should be made and reaction of the soil tested. For example, neither ammonium sulphate nor nitrate of soda is equivalent to NH_4NO_3 in elemental nitrogen content or in reaction (pH). Exclusive and repeated use of the former will acidify the soil; similarly, the latter will tend to neutralize the soil or bring about an alkaline reaction.

6. The general problem of erosion: Since the Ashe Nursery is on sloping land, it will always have to wage an unceasing battle against soil erosion. None of the recommendations listed above are specifically designed to reduce erosion, though most of them will help restore productivity to areas depleted by soil loss; all of them will be less effective to the degree that accelerated erosion continues to gnaw away valuable topsoil.

Badly eroded areas, as well as areas of high erosion potential, might well be taken out of use, concentrating seedling production on the better portions. Under intensified practices, it should be possible to step up seedling production by adopting at least a 2:1 rotation, thus compensating for the reduction in acreage.

Costs

Cost of fumigation with Dowfume W-40 has been about \$60 per acre. With the concentrated Dowfume W-85, this could be reduced to \$50 per acre or less. On a crop of a million seedlings per acre, this

amounts to 5 to 6 cents per thousand, a very nominal cost. Since fumigation is necessary only in spring-sown areas harboring serious infection, this item is insignificant in relation to the benefits.

Cost of fertilizers and soil amendments is somewhat greater but still well within practical limits of operation. Maximum costs of minerals applied per acre are approximately as follows:

600 pounds 32.5 percent ammonium nitrate	\$18.00
3,000 pounds 20 percent superphosphate	50.00
300 pounds 50 percent muriate of potash	12.00
600 pounds 4-8-8 commercial mix	<u>15.00</u>
Total minerals	\$95.00

One-half the cost of spreading, hauling, and mixing 135 cubic yards of sawdust (since sawdust will suffice for 2 pine crops)	<u>\$85.00</u>
Total sawdust and minerals per acre	\$180.00

The sawdust costs are liberal because they are based on a relatively inefficient hand-loading operation, using trucks that averaged only $3\frac{1}{2}$ yards per load. But even on this basis, and assuming a crop of a million seedlings per acre, the cost of minerals and sawdust amounts only to 18 cents per thousand. Thus, the total program for both fumigation and soil improvement costs not more than 25 cents per thousand; or less than 10 percent of the legendary production figure of \$3 per thousand!

Summary

1. The Ashe Nursery study, begun in November 1946, was aimed at controlling root rot and improving soil fertility and seedling size and quality at the Ashe Forest Nursery near Brooklyn, Mississippi.

2. During the 3-year study, approximately 110 standard nursery beds were sown to longleaf, slash, and loblolly pine in various tests on root rot and soil management. Over 200,000 seedlings were individually examined and handled in the laboratory and field, of which over 100,000 were planted in experimental plots. More than 3 million surplus seedlings were supplied for regular planting.

3. Ethylene dibromide ($\text{BrCH}_2\cdot\text{CH}_2\text{Br}$) in a 20 percent (by volume) solution at the rate of 30 to 32 gallons per acre gave excellent control of root rot. Fall sowing of longleaf pine also controlled root rot adequately, and sawdust at the rate of 135 cubic yards per acre (1-inch deep layer) also reduced incidence of disease very materially.

4. Soil fertility investigations indicated that the Ashe soils were deficient particularly in organic matter and phosphorus.

5. Addition of sawdust, ammonium nitrate at the rates of 300 to 600 pounds, 20 percent superphosphate at the rate of 3,000 pounds, and 50 percent muriate of potash at the rate of 240 pounds per acre are deemed a necessary treatment to sustain production of seedlings of satisfactory size and vigor (the minerals to be applied annually, the sawdust triennially).

6. Cost of fumigation with ethylene dibromide amounts to about 5 or 6 cents per thousand, and cost of an adequate mineral and sawdust program about 18 cents per thousand; these costs are based on an estimated production of a million plantable seedlings per nursery acre.

